7B-EL
18

NASA
7N-45-TM
130471
P.13

NATURAL SYSTEMS FOR WASTEWATER TREATMENT AND WATER REUSE FOR SPACE AND EARTHLY APPLICATIONS

B. C. Wolverton
Head, Environmental Research Laboratory

National Space Technology Laboratories
National Aeronautics and Space Administration
NSTL, MS 39529

During the past 15 years, NASA has been conducting research at the National Space Technology Laboratories (NSTL) in Mississippi, on the use of aquatic plants and microorganisms for wastewater treatment and water reuse. Although the primary goal of this research is directed toward future wastewater treatment and water reuse in space, through the NASA Technology Utilization (TU) Program immediate applications are being directed toward problems which exist here on earth.

Water used in all US space missions to date has been either carried on board the spacecraft or generated by fuel cells during flight. Because of the short duration of past missions, on board reclamation and recycling of water has not been a critical factor. With the proposed permanent US manned space station scheduled to be in operation by the 1990's, water reuse could become a critical factor in maintaining this facility.

Although NASA has not recycled water during space flight, several potable water reclamation systems are being ground-tested by NASA for possible use on the Space Station. These include air evaporation where the water is stabilized and fed into an array of wicks. Water vapor is taken up by air flowing over the saturated wicks and is condensed. Another candidate is vapor compression distillation in which the water is stabilized and boiled under low pressure on the inside of a rotating drum. Water vapor is condensed under pressure on the outside of the drum. A thermal, integrated membrane-evaporative system is also undergoing development and testing. Spent water is stabilized and pasteurized in the hot side of a heat exchanger and fed into bundles of hollow, tubular membrane filters. Low pressure maintained outside the filters causes low-temperature vaporization and migration of the water vapor across the membrane. Reclaimed water from all of the above candidate systems must be filtered, polished and disinfected prior to reuse. For more detailed information on these sources see references (1-6).

Wastewater treatment and water reclamation based on the use of aquatic plant-microbial filter (artificial marshes/wetlands) technology is a new, innovative approach to water reuse for space and earthly applications (7). NASA has employed this technology for treating domestic wastewater at NSTL since 1974. Rapid growth in the use of aquatic plants in treating various types of wastewater is evidenced by the many publications in this area during the past several years (8-25).

PRECEDING PAGE BLANK NOT FILMED

BIOLOGY OF AQUATIC PLANT WASTEWATER TREATMENT SYSTEMS

A major part of the treatment process of aquatic plant systems for degrading organics is attributed to microorganisms living on and around the plant root systems.

Once microorganisms are established on aquatic plant roots, in most cases they form a symbiotic relationship with the plants. This relationship normally produces a synergistic effect resulting in increased degradation rates and removal of organic chemicals from the wastewater surrounding the plant root systems. During microbial degradation of the organics, metabolites are produced which the plants absorb and utilize along with nitrogen, phosphorus, and other minerals as a food source. Microorganisms also use some or all metabolites released through plant roots as a food source. By each using the others waste products, this allows a reaction to be sustained in favor of rapid removal of organics from wastewater. Electric charges associated with aquatic plant root hairs also react with opposite charges on colloidal particles such as suspended solids causing them to adhere to the plant roots providing removal from the wastewater stream. Digestion and assimilation of these organic particles is accomplished by the plants and microorganisms. Aquatic plants have the ability to translocate oxygen from the upper leaf areas to the roots producing an aerobic zone around the roots which is desirable in domestic sewage treatment. Aquatic plant roots are also capable of absorbing, concentrating and in some cases translocating toxic heavy metals and certain radioactive elements, therefore, removing them from the water system (26-30). In addition, aquatic plants have demonstrated the ability to absorb certain organic molecules intact where they are translocated and eventually metabolized by plant enzymes as demonstrated with systemic insecticides (31).

The biological reactions which take place between environmental pollutants, plants and microorganisms are numerous and complex, and to date are not fully understood. However, enough information is available to demonstrate that aquatic plants have a broader function than simply supplying a large surface area for microorganisms.

BIO-RECLAMATION OF WASTEWATER IN SPACE

With a permanent space station projected to be in operation by NASA in approximately ten years, numerous approaches to water reclamation/recycling are presently being considered.

Because of the presence of trace levels of organics identified in the environment of closed facilities such as spacecraft and energy-efficient buildings, water reclamation involving condensation must include means of degrading and removing potentially toxic chemicals from water reclaimed in space (32-37).

A plant-microbial aquaculture system, as shown in Figure 1, is demonstrating potential for wastewater treatment, toxic chemical removal and water reuse for space applications. A similar system,

as shown in Figure 2, has also demonstrated potential for many applications in wastewater treatment and water reuse here on earth.

EXPERIMENTAL SYSTEM DESIGN AND OPERATION

The experimental system shown in Figure 2 consists of a plastic tank with a 416 L capacity, which is used as a mixing and settling tank for raw sewage and chemicals. The sewage and/or chemicals are pumped in a continuous flow manner into a metal trough 50.5 cm W, 30.5 cm D, and 298 cm long. This trough contains a 16 cm depth of railroad ballast, 2.5 cm - 7.5 cm in diameter with a top layer 5 cm D of 0.25 cm - 1.3 cm diameter washed gravel. The rock/plant filter is followed by a granular activated carbon filled plastic trough 60 cm W, 30 cm D and 72 cm L. The 4 x 14 mesh activated carbon filter containing reeds (Phragmites communis) has been operational for three years. The operational liquid depth of both plant/rock and plant/carbon filters is 15 cm. Small pumps were used to maintain a 24 h hydraulic retention time through the rock/plant filter while a 11.6 h retention time was maintained through the carbon/reed filter.

RESULTS

Data from NSTL greenhouse experimental artificial marsh wastewater treatment systems have been used to design various types of marsh wastewater treatment systems. The marsh systems shown in Figure 3, Table 1,2, and 3, range in size from several m^3 per day at NSTL to 15,000 m^3 per day at Denham Springs, Louisiana. Extensive operational data from small systems at NSTL and preliminary data from several large systems indicate BOD_5 removal data derived from small systems are valid when scaled up to larger systems. Hydraulic data from large systems containing rock filters indicate that filter widths of 35 m or greater per 277 m length can accommodate daily flow rates up to 947 m^3 without major filter pooling and surface short-circuiting. Rock diameters of 3.0 - 9.0 cm were used in these filters.

SUMMARY

1. The technology for using artificial marsh systems for upgrading domestic sewage effluent from primary settling tanks and/or facultative or aerated lagoons has been sufficiently developed to meet secondary and advanced secondary levels of treatment in the Southern U. S.

2. Artificial marshes using emergent plants such as the bulrush combined with duckweed are also developed to the level of being a promising alternative wastewater treatment system for temperate areas throughout most of the U. S.

3. Three types of artificial marsh wastewater treatment systems are either being installed or are under consideration for use throughout the Southern U. S., see Figure 3.

One system includes a shallow channel with a wastewater depth of 30 cm or less with rooted Southern bulrush (Scirpus californicus) and in some systems, floating duckweed. This system requires a hydraulic retention time of 5-8 days and can function with narrow, long channels. The shallow depth is important to achieve aerobic conditions before effluent discharge. A second type system includes a combination rock-plant filter and requires a reduced hydraulic retention time of 12-48 hours. The rock sizes and filter width-to-length ratio is important because of hydraulic back-pressure created when large volumes of wastewater flow through small rock filters. When large rocks are used, the back-pressure and filter pooling is eliminated, but longer plant growth periods are required for the plant roots to fill the large void area within the rock filter. Optimum wastewater treatment levels may take up to two years to develop when rocks greater than 10 cm are used.

The third and most effective artificial marsh wastewater treatment system includes a combination of open channel rooted plant filters followed by rock-plant filters and can be used for treating a wide variety of wastewater. The retention times can be reduced in both when used in series.

REFERENCES

1. Daniel, S. J., R. L. Sauer, D. L. Pierson, and Y. R. Thorstenson. 1987. Quality requirements for reclaimed/recycled water. NASA TM 58279, NASA/Johnson Space Center, Houston, TX.

2. McDonnell Douglas Astronautics Company: 60-day manned test of a regenerative life support system with oxygen and water recovery. 1968. MD document #CR-98500 available from Biomedical Laboratories Branch (Code SD4), NASA/Johnson Space Center, Houston, TX.

3. McDonnell Douglas Astronautics Company: Test report - Test results Operational ninety-day manned test of a regenerative life support system. 1970. MD document #CR-111881 available from Biomedical Laboratories Branch (Code SD4), NASA/Johnson Space Center, Houston, TX.

4. Committee on Toxicology: Report of the panel on potable water quality in manned spacecraft. 1972. National Ac. of Sci.

5. Zdankiewicz, E. M. and F. H. Schubert. 1984. Development of advanced preprototype vapor compression distillation subsystem (VCDS) for water recovery. Life Sciences Inc., Cleveland, OH. Document #LSI-TR-471-4.

6. Roebelen, G. J. and M. J. Lysaght. 1976. Hollow fiber membrane systems for advanced life support. Document #SVHSER 7100, Biomedical Laboratories Branch, NASA/Johnson Space Center, Houston, TX.

7. Wolverton, B. C. 1980. Higher plants for recycling human waste into food, potable water and revitalized air in a closed life support system. ERL Report No. 192, NASA, NSTL, MS 39529.

8. Bastian, R. K. and S. C. Reed, (Eds.). 1979. Aquaculture Systems for Wastewater Treatment: Seminar Proceedings and Engineering Assessment. U. S. Environmental Protection Agency, EPA 430/9080-006. 485 pp.

9. Gersberg, R. M., B. V. Elkins, S. R. Lyon and C. R. Goldman. 1986. Role of aquatic plants in wastewater treatment by artificial wetlands. Water Res., 20(3):363-368.

10. Inouye, T. 1986. Wetland bacteria speciation and harvesting effects on effluent quality. Final Report. Project No. 3-154-500.00. State Water Resources Control Board, Sacramento, CA. p 114.

11. Reddy, K. R. and W. F. DeBusk. 1985. Nutrient removal potential of selected aquatic macrophytes. J. Environ. Qual., 14(4):459-462.

12. Reddy, K. R. and W. F. DeBusk. 1984. Growth characteristics of aquatic macrophytes cultured in nutrient-enriched water: I. water hyacinth, water lettuce, and pennywort. Econ. Bot., 38(2):229-239.

13. Reddy, K. R. and W. F. DeBusk. 1985. Growth characteristics of aquatic macrophytes cultured in nutrient-enriched water: II. azolla, duckweed, and salvinia. Econ. Bot., 39(2):200-208.

14. Reddy, K. R. and W. H. Smith (Eds.), Aquatic plants for wastewater treatment and resource recovery. Magnolia Publishing Inc., Orlando, FL. pp. 1-1032.

15. Wolverton, B. C. And R. C. McDonald. 1979. Upgrading facultative wastewater lagoons with vascular aquatic plants. J. Water Pollut. Cont. Fed., 51(2):305-313.

16. Wolverton, B. C. and R. C. McDonald. 1981. Energy from vascular plants wastewater treatment systems. Econ. Bot., 35(2):224-232.

17. Wolverton, B. C. and R. C. McDonald. 1981. Natural processes for treatment of organic chemical waste. The Environ. Prof., 3:99-104.

18. Wolverton, B. C. 1982. Hybrid wastewater treatment system using an aerobic microorganisms and reed (Phragmites communis). Econ. Bot., 36(4):373-380.

19. Wolverton, B. C., R. C. McDonald and W. R. Duffer. 1983. Microorganisms and high plants for wastewater treatment. J. Environ. Qual., 12(2):236-242.

20. Wolverton, B. C., R. C. McDonald, C. C. Myrick, and K. M. Johnson. 1984. Upgrading septic tanks using microbial/plant filters. J. MS Acad. Sci., 29:19-25.

21. Wolverton, B. C., R. C. McDonald and L. K. Marble. 1984. Removal of benzene and its derivatives from polluted water using the reed/microbial filter technique. J. MS Acad. Sci., 29:119-127.

22. Wolverton, B. C. and R. C. McDonald-McCaleb. 1986. Biotransformation of priority pollutants using biofilms and vascular plants. J. MS Acad. Sci. 31:79-89.

23. Wolverton, B. C. 1987. Aquatic plants for wastewater treatment: an overview. In: K. R. Reddy and W. H. Smith (Eds.), Aquatic plants for wastewater treatment and resource recovery. Magnolia Publishing Inc., Orlando, FL. pp. 3-15.

24. Wolverton, B. C. 1987. Artificial marshes for wastewater treatment. In: K. R. Reddy and W. H. Smith (Eds.), Aquatic plants for wastewater treatment and resource recovery. Magnolia Publishing Inc., Orlando, FL. pp. 141-152.

25. Wolverton, B. C. and R. C. McCaleb. 1987. Pennywort and duckweed marsh system for upgrading wastewater effluent from a mechanical package plant. In: K. R. Reddy and W. H. Smith (Eds.), Aquatic plants for wastewater treatment and resource recovery. Magnolia Publishing Inc., Orlando, FL. pp. 289-294.

26. Wolverton, B. C. and R. C. McDonald. 1978. Water hyacinth sorption rates of lead, mercury and cadmium. ERL Report No. 170. NASA, NSTL, MS.

27. Wolverton, B. C., R. M. Barlow, and R. C. McDonald. 1976. Application of vascular aquatic plants for pollution removal, energy, and food production. 141. In: J. Tourbier and R. W. Pierson, Jr., (Eds.). Biological Control of Water Pollution. University of Pennsylvania Press, Philadelphia, PA.

28. McDonald, R. C. 1981. Vascular plants for decontaminating radioactive water and soils. NASA Tech. Memorandum, TM-X-72740, NSTL, MS.

29. Dierberg, F. E., T. A. Debusk, and N. A. Goulet, Jr. 1987. Removal of copper and lead using a thin-film technique. In: K. R. Reddy and W. H. Smith (Eds.), Aquatic plants for wastewater treatment and resource recovery. Magnolia Publishing Inc., Orlando, FL. pp. 497-504.

30. Heaton, C., J. Frame, and J. K. Hardy. 1987. Lead uptake by the water hyacinth. In: K. R. Reddy and W. H. Smith (Eds.), Aquatic plants for wastewater treatment and resource recovery. Magnolia Publishing Inc., Orlando, FL. pp. 463-470.

31. Wolverton, B. C. and D. D. Harrison. 1973. Aquatic plants for removal of mevinphos from the aquatic environment. J. MS Acad. Sci., 19:84.

32. National Aeronautics and Space Administration. 1974. The Proceedings of the Skylab Life Sciences Symposium, August 27-29, 1974. NASA Tech. Memorandum, TM-X-58154, Johnson Space Center, TX, 161-168.

33. Gammage, R. B. and S. V. Kaye (Eds.). 1984. Indoor Air and Human Health. Proceedings of the Seventh Life Sciences Symposium, Knoxville, TN, October 29-31, 1984. Lewis Publishers, Inc., Chelsea, MI.

34. Walsh, C., S. Dudney and E. D. Copenhauer. 1984. Indoor Air Quality. CRC Press, Inc., Boca Raton, FL.

35. Wallace, L., R. Zweidinger, M. Erickson, S. Cooper, D. Whittaker, and E. Pellizzari. 1982. Monitoring individual exposure: measurements of volatile organic compounds in breathing-zone air, drinking water, and exhaled breath. Env. In., 8:269-282.

36. Wolverton, B. C., R. C. McDonald, and E. A. Watkins, Jr. 1984. Foliage plants for removing indoor air pollutants from energy efficient homes. Econ. Bot., 38(2):224-228.

37. Wolverton, B. C., R. C. McDonald, and H. H. Mesick. 1985. Foliage plants for the indoor removal of the primary combustion gases carbon dioxide and nitrogen dioxide. J. MS Acad. Sci., 30:1-8.

TABLE 1. ARTIFICIAL MARSHES FOR TREATING DISCHARGED WASTEWATER FROM SEWAGE LAGOON AND/OR SEPTIC TANKS.

MARSH PLANTS	RETENTION TIME HRS	DISSOLVED OXYGEN* (DO) mg/L		BOD$_5$ mg/L		TEMP. $^\circ$C
		Inf.	Eff.	Inf.	Eff.	Average
Arrowhead (Sagittaria latifolia)	24	1.3	2.2	53	2	20
Pickerelweed (Pontederia cordata)	24	0.85	2.1	47	8	27
Canna Lily (Canna flaccida)	24	2.5	3.2	42	3	20
Southern bulrush (Scirpus californicus)	24	2.7	4.1	90	16	21
Torpedo grass (Panicum repens)	24	3.0	4.0	115	23	22

*Average data from two months continuous flow studies.

TABLE 2. ARTIFICIAL MARSH WASTEWATER TREATMENT SYSTEM USING COMBINED PLANT/ROCK
AND PLANT/CARBON FILTERS.* See FIGURE 2.

| | Torpedo grass/Rock Filter | | | Reed/Granular Carbon Filter |
	#1 Inf	#2 Eff		#3 Eff
pH	7.46	7.11		6.87
DO, mg/L	3.35	4.02		5.00
Temp, °C	26.4	25.9		26.2
TSS, mg/L	20.0	5.0		3.0
TDS, mg/L	532.0	323.0		290.0
BOD$_5$, mg/L	130.6	15.0		1.9
NH$_3$-N, mg/L	15.88	13.05		7.18
TOC, mg/L	72.67	32.80		12.73
Trichloroethylene, ppm	3.60	0.0009		<0.0001
Benzene, ppm	7.04	1.52		0.0003
Chlorobenzene, ppm	4.85	1.54		0.0016
Toluene, ppm	5.62	1.37		0.0009

*Average data from four different sampling days.

TABLE 3. ARTIFICIAL MARSH WASTEWATER TREATMENT SYSTEM USING COMBINED PLANT/ROCK
         AND PLANT/CARBON FILTERS.* See FIGURE 2.

| | Bulrush/Rock Filter | | Reed/Granular Carbon Filter |
	#1 Inf	#2 Eff	#3 Eff
pH	6.78	6.62	6.56
DO, mg/L	1.9	4.3	5.0
Temp, °C	21.0	20.5	19.8
TSS, mg/L	39.0	10.0	0.0
TDS, mg/L	403.0	357.0	310.0
BOD$_5$, mg/L	103.0	12.7	<1.0
NH$_3$-N, mg/L	29.0	16.7	2.3
TOC, mg/L	70.0	33.0	13.0
Trichloroethylene, ppm	9.9	0.05	<0.0001
Benzene, ppm	12.0	5.1	0.0005
Toluene, ppm	11.47	4.5	0.0035
Chlorobenzene, ppm	10.65	4.9	0.0050

*Average data from four different sampling days.

738

FIGURE 1

CUCUMBER PLANTS

SWEET POTATO PLANTS

CIRCULATION PUMP

DETAIL
SWEET POTATO

BERMUDA GRASS

FILTER
SCREEN

GRANULAR ACTIVATED
CARBON FILTER

UV LIGHT
STERILIZATION FILTER

PURIFIED WATER
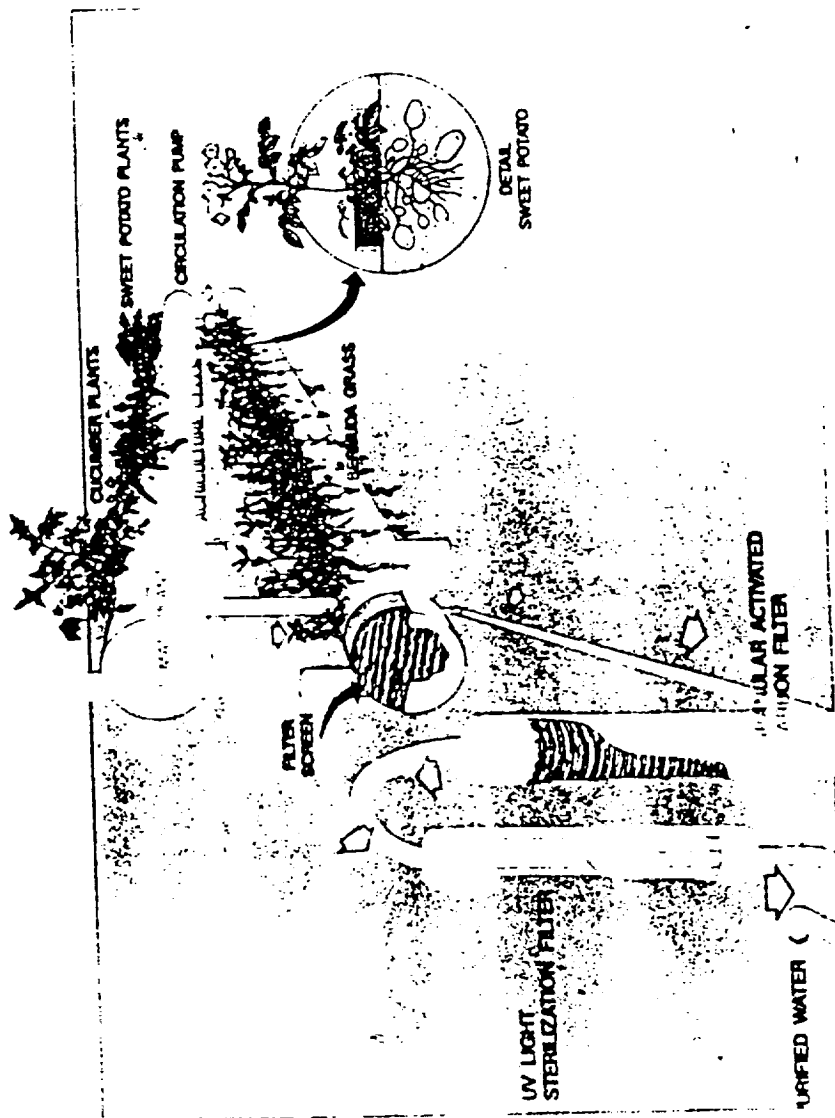
ARTIFICIAL MARSH WATER TREATMENT AND WATER REUSE SYSTEM

REED

BULRUSH

PUMP

STORAGE TANK

SAMPLING POINT #1

SAMPLING POINT #2
24-HOUR RETENTION

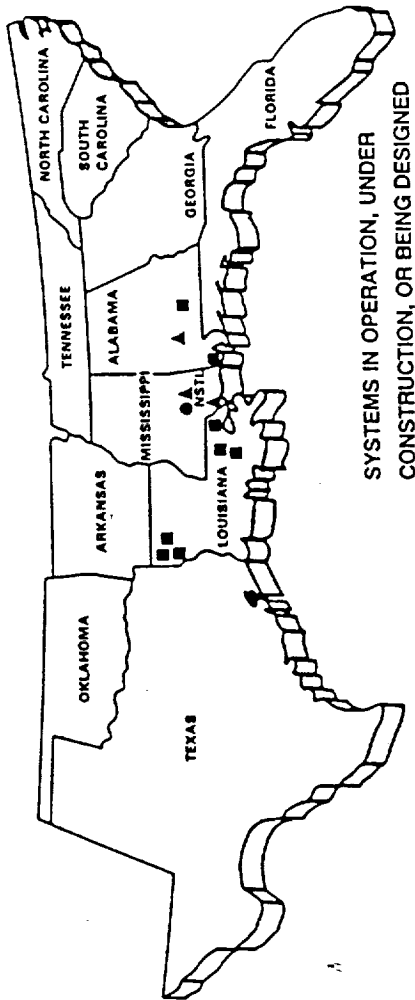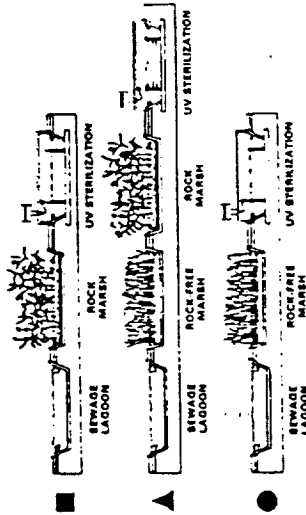SAMPLING POINT #3
11.6-HOUR RETENTION
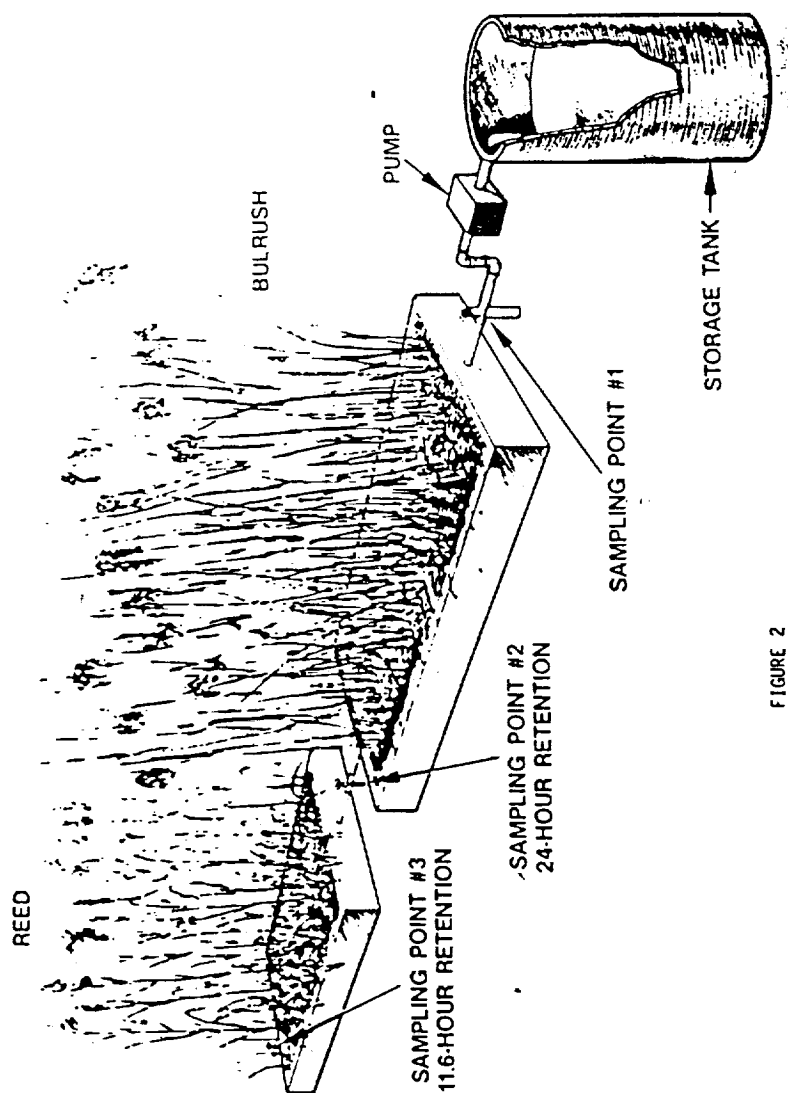
FIGURE 2

ARTIFICIAL MARSH WASTEWATER TREATMENT SYSTEM

SYSTEMS IN OPERATION, UNDER CONSTRUCTION, OR BEING DESIGNED

- HAUGHTON, LA
- BENTON, LA
- SIBLEY, LA
- MANDEVILLE, LA
- DENHAM SPRINGS, LA
- CARVILLE, LA

- COLLINS, MS
- VREDENBURGH, AL
- LUVERNE, AL
- THEODORE, AL
- NATIONAL SPACE TECHNOLOGY LABORATORIES, MS

SEWAGE LAGOON · ROCK-FREE MARSH · ROCK MARSH · UV STERILIZATION

FIGURE 3

741